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PREDICTION FOR BARK BEETLES CAUSED DESICCATION OF PINE STANDS

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The aim of the study was to develop an algorithm predicting the spread of bark beetles caused desiccation and to test it on the example of Teteriv Forest Enterprise. A set of parameters was tested, particularly proportion of pine in the forest composition, stand age, a relative density of stocking, stand origin and type of forest site conditions. Pine proportion in the forest composition and pine age have the greatest importance for prediction the threat of bark beetles caused desiccation. The relative density of stocking by itself is a less important risk factor than its sudden decrease. Prediction accuracy increases, if we consider the bordering of compartments with clear-cuts after main felling or clear sanitary felling of the last two years. Using a simplified scale (of two main parameters – pine proportion and pine age) gives the possibility to recognize the trend of foci area dynamics or to compare it for different administrative regions or natural zones. Confinement of bark beetles foci to specific subcompartments can be predicted by GIS tools using the suggested algorithm, forest inventory database and digitized maps.
Key words: Scots pine (*Pinus sylvestris* L.), bark beetles caused desiccation, proportion of pine in the forest composition, stand age, relative density of stocking, stand origin, forest site conditions, bordering clear-cuts.

Introduction. In recent years, forest desiccation has been registered in many regions (Bigler et al. 2006, Wermelinger et al. 2008, Faccoli et al. 2011, 2012, Colombari et al. 2013, Siitonen 2014, Sazonov et al. 2017), including Ukraine, where decline of Scots pine (*Pinus sylvestris* L.) covered almost all Polissya (Borodavka et al. 2016, 2017). Climate change and anthropogenic pressure are the main preconditions of this phenomenon (Getmanchuk et al. 2017, Pineau et al. 2017). However, tree mortality often happens after their infestation by stem insects together with pathogens, which they vector (Davydenko et al. 2017). Infested trees die during several weeks (Colombari et al. 2013, Borodavka et al. 2016, Meshkova & Borysenko 2017), therefore it is very important to detect such trees in time. This phenomenon was named bark beetles caused desiccation (Sazonov & Zvyagintsev 2016). Among bark beetles populating pine, in recent years, two species have predominantly spread. They are pine engraver beetle *Ips acuminatus* (Gyllenhal, 1827) and six-toothed bark beetle *Ips sexdentatus* (Boerner, 1767) (Coleoptera: Curculionidae: Scolytinae). Both the species have at least two main generations per year as well as sister generations. When the temperature rises, the number of generations increases (Meshkova et al. 2015, 2017, Pineau et al. 2017). Susceptible trees may be infested by these species throughout the growing season. Usually, the attacks of *Ips sexdentatus* are in butt part of the stem and are easily detectable. At the same time, *Ips acuminatus* colonizes branches and tree tops as well as parts of a stem with thin bark, although at high population density, as well as in felled or windthrown trees it attacks also parts of a stem with transition bark (Meshkova et al. 2015, 2017). Therefore it is possible to recognize the attacked tree only after crown discoloration.

Prediction of bark beetles spread is based on understanding their preferences for environmental conditions connected with forest site conditions, forest age, tree species composition, the relative density of stocking, etc.

For the foci of bark beetles caused desiccation, the formation of “spots” from several trees is characteristic. As the outbreak develops, the area of each "spot" increases and the distance between them decreases (Colombari et al. 2013). In the absence nearby a sufficient number of susceptible trees, bark beetles fly long distances, the population is scattered, and the outbreak collapses. If nearby many trees are weakened or dead as a result of drought, fire or management, then bark beetles fly there, colonizes such trees, harvested and not taken out timber and wood debris. Therefore the outbreak goes on (Faccoli et al. 2012, Meshkova & Borysenko 2017).

Clear-cuts with wood debris and weakened trees around the perimeter are one of the preferred places for bark beetles attack (Meshkova & Sokolova 2017).

In Steppe and Left-bank Forest Steppe felled and fallen branches and tops run dry, and bark beetles progeny die (Meshkova et al. 2015). In Polissya such branches and tops on the ground retain moisture for a long time, and *I. acuminatus* successfully completes its development even in the branches with a diameter of 1.5 cm (Meshkova & Borysenko 2017).

In 2014–2017 we studied spatial dynamics of bark beetles caused desiccation in the State Enterprise "Teteriv Forest Economy" and revealed the characteristics of stands, which are the most favorable for bark beetles (Meshkova & Borysenko 2017).

The aim was to develop and to test an algorithm for predicting the spread of bark beetles caused desiccation on the example of Teteriv Forestry of the State Enterprise "Teteriv Forest Economy".

Materials and Methods. Th research was carried out in 2014–2017 in the stands of Scots pine in the Teteriv Forest Enterprise (Kyiv region). Dynamics of forest decline was studied on the base of monitoring data of forest health condition and of selective and clear sanitary felling in the stands. To evaluate the threat of bark beetles caused desiccation, data on forest fund, especially on the pine stands area were taken from the forest inventory database as of 2014. Reliability of prediction of the threat of bark beetles caused desiccation was evaluated as a percentage of common subcompartments in two sets of subcompartments (with observed and predicted foci of bark beetles caused desiccation) from the number of compartments with actual foci of bark beetles.

Spatial analysis of forest decline "spots" distribution was carried out using QGIS 2.18 (QGIS Development Team 2017).

Results and Discussion. Analysis of the data on bark beetles caused desiccation for 4 years allowed ranking all studied parameters by 6 grades of threat: 0 points – absent, 1 point – very low, 2 points – low, 3 points – moderate, 4 points – high, 5 points – very high (Table 1).

Table 1

Scoring of pine stands by preferences for bark beetles

Parameters	Threat of bark beetles caused desiccation, points					
	0 – absent	1 – very low	2 – low	3 – moderate	4 – high	5 – very high
Stand origin	–	–	–	–	plantations	natural
Type of forest site conditions	A_1, B_1, D_1–D_5	A_2, A_5, B_5, C_5	A_3–A_4	B_2, C_2	B_3, C_3, B_4, C_4	–
Stand age, years	≤ 40	41–50	51–60	61–70	71–90	>90
Relative density of stocking	≤ 0.4	0.5	0.9–1.0	0.6	0.8	0.7
Proportion of pine in the forest composition	≤ 5	6	7	8	9	10

Notes: A, B, C, D – poor, relatively poor, relatively fertile, fertile forest site conditions;
1, 2, 3, 4, 5 – dry, fresh, humid, wet, swamp forest site conditions.

For each compartment, respective parameter values were replaced by points according to Table 1 and counted the amount, which then ranked by 5 grades. If a subcompartment was adjacent to clear-cut after main felling or clear sanitary felling for the last two years, the threat score was increased by one point.

Calculations considering all forest lands of Teteriv forestry show that bark beetles caused desiccation cannot spread in 12.6 % of area because land categories there include lawns, nurseries, roads, buildings, unclosed pine plantations or closed forest stands where *P. sylvestris* is not the main forest forming species or is represented by less than 50 % in the tree species composition (Table 2). None of the subcompartments received a total score of "1". The subcompartments with a high threat of bark beetles caused desiccation took the highest percentage (49.9 and 41.2 % in the cases considering and not considering bordering with clear-cuts respectively).

One can see that in the case of considering bordering with clear-cuts, the proportion of area with a low, moderate and high threat of bark beetles caused desiccation decreases and the proportion of area with very high threat increases. The area of subcompartments with the very high threat (5 points) becomes 715.7 hectares more (15.3 %), with 5–6 points – 890.1 hectares more (19 %).

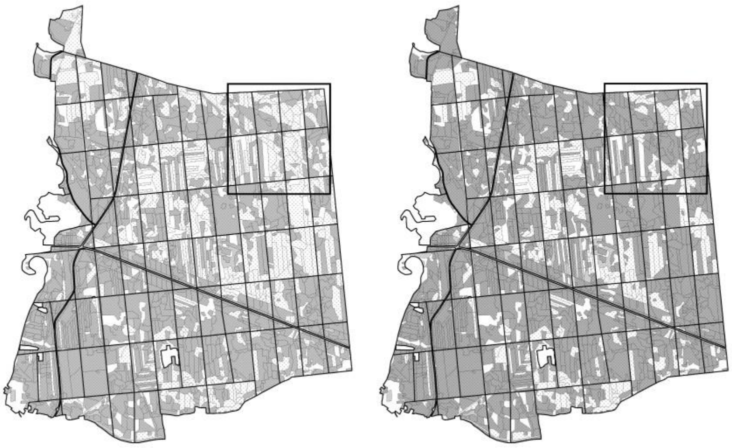
Obtained data were used to thematic maps creation according to the predicted spread of bark beetles caused desiccation of pine stands (Fig. 1). Fig. 2 shows enlarged fragments of the maps presented in Fig. 1.

Table 2

Calculation of all subcompartments of Teteriv Forestry by attractiveness for bark beetles

Considering bordering with clear-cuts	Threat of bark beetles caused desiccation: numerator – area, hectares; denominator – proportion, %							Total
	0 – absent	1 – very low	2 – low	3 – moderate	4 – high	5 – very high	6 – comple-mentary*	
Absent	588.3 / 12.6	–	33.0 / 0.7	1194.0 / 25.5	2335.3 / 49.9	533.9 / 11.4	–	4684.5 / 100
Present	588.3 / 12.6	–	12.2 / 0.3	728.8 / 15.6	1931.2 / 41.2	1249.6 / 26.7	174.4 / 3.7	4684.5 / 100
Difference	–	–	-20.8/ -0.4	-465.2/ -9.9	-404.1/ -8.6	715.7/ 15.3	174.4/ 3.7	–

Note: 6 points assigned to compartments evaluated with 5 points and adjacent to clear-cut.



a *b*

Fig. 1 – Distribution of the stands of Teteriv forestry by the threat of pine engraver beetle foci: *a* – without considering bordering with clear-cuts; *b* – considering bordering with clear-cuts; the rectangles show the fragments presented in Fig. 2

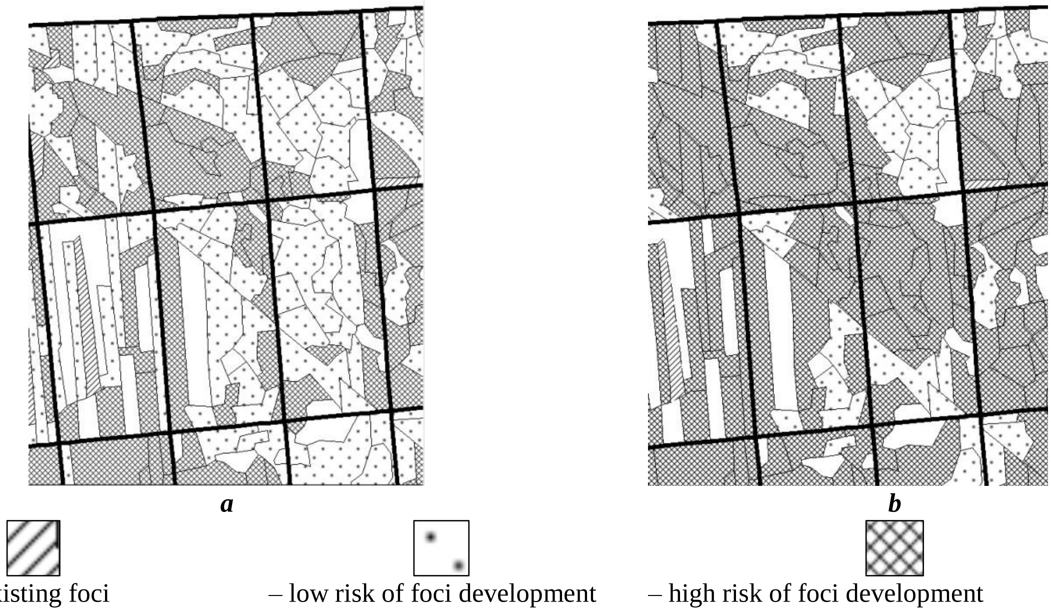


Fig. 2 – Enlarged fragments of the map (see Fig. 1) on distribution of Teteriv forestry stands by the threat of pine engraver beetle foci: *a* – without considering bordering with clear-cuts; *b* – considering bordering with clear-cuts

To reveal the most important factors influencing the vulnerability of stands to bark beetles infestation, the sets of plots with observed and predicted forest decline (by different parameters) were compared.

Calculations show that prediction using the set of all parameters mentioned in Table 1 (proportion of pine in the forest composition, stand age, the relative density of stocking, stand origin and type of forest site conditions) makes it possible to reliably identify subcompartments with high threat of bark beetles caused desiccation (Table 3). Predicted area increased if we consider the bordering of compartments with clear-cuts.

Table 3

Reliability of prediction of the threat of bark beetles caused desiccation in pine stands, considering certain parameters (calculated for Teteriv forestry)

Forest parameters	All subcompartments	Subcompartments, which border with clear-cut area
All parameters	100.0	27.8
Proportion of pine in the forest composition – “100 %” (pure Scots pine stand)	57.6	16.3
Stand age, years – “over 70 years old”	52.3	11.5
Relative density of stocking – “0.7”	36.7	12.2
Stand origin – “natural”	36.5	7.2
Type of forest site conditions – relatively poor humid and wet forest site conditions	0.2	0.0

The analysis shows that the proportion of pines in the forest composition has the greatest importance for prediction the threat of bark beetles caused desiccation in pine stands (pure pine stands are infested first of all) as well as their age (see Table 3).

Although we have found infested by *Ips acuminatus* 15–20 years old pines, but the massive decline of such stands did not happen. It may be explained by their high density and shading of a considerable part of stems. However, in the case of intensive thinning the risk of such stands infestation exists.

The relative density of stocking by itself is a less important risk factor than its sudden decrease: the reliability of infestation of the compartments bordering with clear-cuts increases by 12.2 % (see Table 3).

Considering stand origin significantly increases the reliability of the prediction (by 36.5 %). However, it may be taken into account that mean age of natural pine stands in Teteriv Forest Enterprise is more than twice as large as artificial ones. That is, the vulnerability of stands in separate subcompartments to bark beetles infestation may more depend on stand age than on their origin (see Table 3).

The type of forest site conditions plays the smallest role in predicting the distribution of bark beetles infestation (see Table 3).

Thus, the six-point scale of prediction of bark beetles caused desiccation can be simplified to four points and two main parameters (Table 4).

Table 4

A simplified scale to predict the threat of bark beetles caused desiccation of pine stands

Forest parameters	Threat of foci spread, points			
	low	moderate	high	very high
Age, years	≤ 50	51–70	71–90	> 90
Pine proportion in the stand composition, %	≤ 60	61–80	81–90	91–100

Using the simplified scale gives the possibility to recognize the trend of foci area dynamics or to compare it for administrative regions or natural zones.

So, in the forest fund of Teteriv Forest Enterprise, pine stands of over 70 years old make up 37.3 % of the area, and among bark beetles foci of 2015–2016 they make up 84.6 % of the area.

Pure pine stands make up 47.2 and 42.1 % of area among plantations and natural stands, and bark beetles foci in them make up 63.2 and 66.4 % of the area.

At the same time, confinement of bark beetles foci to specific subcompartments can be revealed only by analysis of forest inventory database. In the presence of a digitized map, it may be done by GIS tools. Our calculations show that in Teteriv Forest Enterprise, pure pine stands older than 70 years are presented in 40.8 % of compartments covered by bark beetles caused desiccation.

Our researches made it possible to develop an algorithm for the prediction of the distribution of bark beetles caused desiccation foci.

In the first stage, the forest inventory database analysis reveals the subcompartments of the maximum risk considering the stand age, pine proportion in the stand composition and relative density of stocking.

Corrections to prediction are introduced as additional risk areas appear, particularly clear-cuts after main felling and clear sanitary felling, as well as gaps in forest canopy due to the construction of buildings, roads, installation of fire canopy ruptures, tree felling under power lines, etc. Such plots can be revealed using video surveillance cameras, drones and to correct information during a ground inspection of a forest as well as by a ground survey.

The suggested algorithm was included into information system of forest protection from fires and forest pests monitoring, and respective software was developed.

Conclusions. Using the set of parameters (proportion of pine in the forest composition, stand age, the relative density of stocking, stand origin and forest site conditions) makes it possible to reliably identify subcompartments with a high threat of bark beetles caused desiccation.

Pine proportion in the forest composition and its age has the greatest importance for prediction the threat of bark beetles caused desiccation in pine stands.

The relative density of stocking by itself is a less important risk factor than its sudden decrease.

Prediction accuracy increases if we consider the bordering of compartments with clear-cuts after main felling and clear sanitary felling.

Using the simplified scale (of four points and two main parameters) gives the possibility to recognize the trend of foci area dynamics or to compare it for administrative regions or natural zones.

Confinement of bark beetles foci to specific subcompartments can be predicted by GIS tools using the suggested algorithm, forest inventory database and digitized maps.

REFERENCES – ПОСИЛАННЯ

Bigler, C., Bräker, O. U., Bugmann, H., Dobbertin, M., Rigling, A. 2006. Drought as an inciting mortality factor in Scots pine stands of the Valais, Switzerland. Ecosystems, 9: 330–343. http:// dx.doi.org/10.1007/s10021-005-0126-2.

Borodavka, V., Getmanchuk, A., Bortnik, T., Kychylyuk, O., Voytyuk, V. 2017. Novyy patohennyy kompleks sosnovykh lisiv Volynsʹkoho Polissya [New pathogenic complex of pine-forests of Volyn Polissia]. Naukovyy visnyk Skhidnoyevropeysʹkoho natsionalʹnoho universytetu imeni Lesi Ukrayinky [Scientific herald of the Lesia Ukrainka Eastern European National University], 7: 23–31 (in Ukrainian).

Borodavka, V. O., Getmanchuk, A. I., Kychyljuk, O. V., Vojtjuk, V. P. 2016. Patologichni procesy u vsyhayuchyh sosnovyh nasadzhennyah Volynskogo Polissya [Pathological processes of declining pine stands in Volyn Polissya]. Naukovyy visnyk NUBiP Ukrainy. Serija Lisivnyctvo ta dekoratyvne sadivnyctvo [Scientific Herald of NULES of Ukraine. Series: Forestry and decorative gardening], 238: 102–118 (in Ukrainian). http://nbuv.gov.ua/UJRN/nvnau_lis_2016_238_14.

Colombari, F., Schroeder, M. L., Battisti, A, Faccoli, M. 2013. Spatio-temporal dynamics of an *Ips acuminatus* outbreak and implications for management. Agricultural and Forest Entomology, 15: 34–42. doi: 10.1111/j.1461-9563.2012.00589.x.

Davydenko, K., Vasaitis, R., Menkis, A. 2017. Fungi associated with *Ips acuminatus* (Coleoptera: Curculionidae) in Ukraine with a special emphasis on pathogenicity of ophiostomatoid species. European Journal of Entomology, 114: 77–85. doi: 10.14411/eje.2017.011.

Faccoli, M., Finozzi, V., Colombari, F. 2012. Effectiveness of different trapping protocols for outbreak management of the engraver pine beetle *Ips acuminatus* (Curculionidae, Scolytinae). International Journal of Pest Management, 58(3): 267–273. doi: 10.1080/09670874.2011.642824.

Faccoli, M., Finozzi, V., Gatto, P. 2011. Sanitation felling and helicopter harvesting of bark beetle-infested trees in Alpine forests: an assessment of the economic costs. Forest Products Journal, 61(8): 675–680. doi: 10.13073/0015-7473-61.8.675.

Getmanchuk, A., Kychylyuk, O., Voytyuk, V., Borodavka, V. 2017. Rehionalni zminy klimatu yak prychyna hostrykh vsykhan′ sosnyakiv Volynskoho Polissya [Regional climate changes as primary cause of pine stands decline in Volyn Polissya]. Naukovyy visnyk NLTU Ukrayiny [Scientific Bulletin of UNFU], 27(1): 120–124 (in Ukrainian).

Meshkova, V. L. and Borysenko, O. I. 2017. Dynamics of pine engraver beetle-caused forest decline in Teterivske Forestry Enterprise. Lisivnytstvo i ahrolisomelioratsiya [Forestry and Forest Melioration], 131: 171–178.

Meshkova, V. L., Kochetova, A. I., Zinchenko, O. V. 2015. Verkhivkovyy koroyid *Ips acuminatus* (Gyllenhal, 1827): Insecta: Coleoptera: Scolytinae u Pivnichno-Skhidnomu Stepu Ukrayiny [The pine engraver beetle *Ips acuminatus* (Gyllenhal, 1827) (Coleoptera: Curculionidae: Scolytinae) in the NorthEastern Steppe of Ukraine]. The Kharkov Entomol. Soc. Gaz., 23(2): 64–69 (in Ukrainian).

Meshkova, V. L., Kochetova, A. I., Zinchenko, O. V., Skrylnik, Yu. Ye. 2017. Biology of multivoltine bark beetles species (Coleoptera: Scolytinae) in the North-Eastern Steppe of the Ukraine. The Bulletin of Kharkiv National Agrarian University. Series “Phytopathology and Entomology”, 1–2: 117–124.

Meshkova, V. L. and Sokolova I. M. 2017. Stovburovi shkidnyky nezimknenykh sosnovykh kultur u prydonetskykh borakh [Stem pests of unclosed pine forests in Siversky Donets river valley]. Kharkiv, Planeta-Print, 160 p. (in Ukrainian).

Pineau, X., David, G., Peter, Z., Sallé, A., Baude, M., Lieutier, F., Jactel, H. 2017. Effect of temperature on the reproductive success, developmental rate and brood characteristics of *Ips sexdentatus* (Boern.). Agricultural and Forest Entomology, 19(1): 23–33.

QGIS Development Team. (2017). Quantum GIS vs 2.18. Open Source Geospatial Foundation Project.

Sazonov, A. A., Kukhta, V. N., Tapchevskaya, V. A. 2017. Vspyshka massovogo razmnozheniya vershinnogo koroyeda (*Ips acuminatus* (Gyllenhal, 1827), Scolytinae, Coleoptera) v lesakh Belorusskogo Poles’ya [Outbreak of pine engraver beetle (*Ips acuminatus* (Gyllenhal, 1827), Scolytinae, Coleoptera) in forests of the Belarus Polesye]. In: Borodin, O. I., Tsinkevich, V. A., Varaksin, A. N. (Eds.). Itogi i perspektivy razvitiya entomologii v Vostochnoy Yevrope: sbornik statey II Mezhdunarodnoy nauchno-prakticheskoy konferentsii [Results and perspectives of development of entomology in Eastern Europe: a collection of articles of the II International Scientific and Practical Conference], September 6–8, 2017, Minsk, p. 366–378 (in Russian).

Sazonov, A. and Zvyagintsev, V. 2016. Kak tushit biologicheskiy pozhar? [How to extinguish a biological fire?]. Lesnoye i okhotnich’ye khozyaystvo [Forestry and hunting], 8: 26–32 (in Russian).

Siitonen, J. 2014. *Ips acuminatus* kills pines in southern Finland. Silva Fennica, 48 (4), article id 1145, 7 p. http://dx.doi.org/10.14214/sf.1145.

Wermelinger, B., Rigling, A., Schneider, M. D., Dobbertin, M. 2008. Assessing the role of bark- and wood-boring insects in the decline of Scots pine (*Pinus sylvestris*) in the Swiss Rhone valley. Ecological Entomology, 33: 239‒249. http://dx.doi.org/10.1111/j.1365- 2311.2007.00960.x.

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ПРОГНОЗУВАННЯ СПРИЧИНЕНОГО КОРОЇДАМИ ВСИХАННЯ СОСНОВИХ ЛІСІВ

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Метою досліджень було розроблення алгоритму прогнозування поширення спричиненого короїдами всихання та тестування його на прикладі ДП «Тетерівське ЛГ». Тестували як параметри для прогнозування частку сосни в складі насаджень, вік насаджень, відносну повноту, походження насаджень і тип лісорослинних умов. Частка сосни в складі насаджень та їхній вік мають найбільшу значущість під час прогнозування загрози поширення спричиненого короїдами всихання. Сама відносна повнота є менш важливим чинником впливу, ніж її раптове зменшення. Точність прогнозування зростає, якщо враховувати межування виділів із зрубами, утвореними після рубок головного користування та суцільних санітарних рубок останніх двох років. Використання спрощеної шкали (що містить два основні параметри – частку сосни в складі насаджень та їхній вік) дає можливість визначити тренд динаміки площі осередків усихання та порівняти її для різних адміністративних областей або природних зон. Приуроченість осередків короїдів до окремих виділів можливо (доцільно) прогнозувати засобами ГІС із використанням запропонованого алгоритму, бази даних лісовпорядкування та оцифрованих карт.

Ключові слова: сосна звичайна (*Pinus sylvestris* L.), спричинене короїдами всихання, частка сосни у складі насаджень, вік насаджень, відносна повнота, походження насадження, тип лісорослинних умов, межування зі зрубами.

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ПРОГНОЗИРОВАНИЕ ВЫЗВАННОГО КОРОЕДАМИ УСЫХАНИЯ СОСНОВЫХ ЛЕСОВ

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Целью исследований была разработка алгоритма прогнозирования распространения вызванного короедами усыхания и тестирование его на примере ГП «Тетеревское ЛХ». Тестировали в качестве параметров для прогнозирования долю сосны в составе насаждений, возраст насаждений, относительную полноту, происхождение насаждений и тип лесорастительных условий. Доля сосны в составе насаждений и их возраст имеют наибольшую значимость при прогнозировании угрозы распространения вызванного короедами усыхания. Относительная полнота как таковая является менее важным фактором влияния, чем ее внезапное уменьшение. Точность прогнозирования возрастает, если учитывать соседство выделов с вырубками рубок главного пользования и сплошных санитарных рубок последних двух лет. Применение упрощенной шкалы (включающей два основных параметра – долю сосны в составе насаждений и их возраст) дает возможность определить тренд динамики площади очагов усыхания и сравнить ее для разных административных областей или природных зон. Приуроченность очагов короедов к отдельным выделам возможно прогнозировать средствами ГИС с использованием предложенного алгоритма, базы данных лесоустройства и оцифрованных карт.

Ключевые слова: сосна обыкновенная (*Pinus sylvestris* L.), вызванное короедами усыхание, доля сосны в составе насаждений, возраст насаждений, относительная полнота, происхождение насаждения, тип лесорастительных условий, соседство с вырубками.

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